



Regolith-Derived Heat Shield for Planetary Body Entry and Descent System with In-Situ Fabrication

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Introduction



- High-mass planetary surface access is one of NASA's Grand Challenges involving entry, descent, and landing (EDL).
- Heat shields fabricated in-situ can provide a thermal protection system for spacecraft that routinely enter a planetary atmosphere.
- Fabricating the heat shield from extraterrestrial regolith will avoid the costs of launching the heat shield mass from Earth.
- This project investigated three methods to fabricate heat shield using extraterrestrial regolith and performed preliminary work on mission architectures.

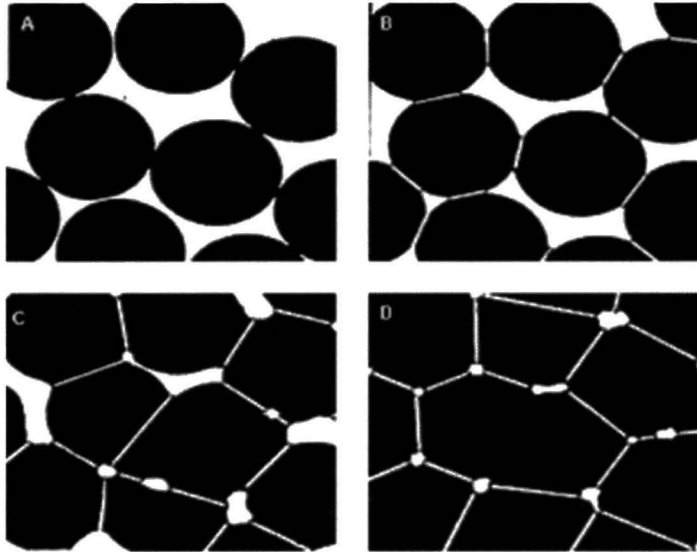


Fabrication Methods Being Investigated

- Sintering of regolith
 - Furnace sintering
 - Solar sintering
- Hot post-process regolith from in-situ resource utilization (ISRU) devices.
 - ISRU processes to derive O_2 and other materials from regolith leaves a hot slag or glassy melt as a waste stream.
 - This hot regolith can be poured into a heat shield mold form.
- High temperature polymer binder



Sintering Process



Temperature and heating time are crucial factors in resulting structure.

JSC-1AC regolith
simulant sintered tiles





ISRU Process Waste



Use of waste stream from ISRU processes.

- Hot regolith can be poured into a heat shield mold.
- Saves energy by combining processes.

We discarded the use of fully melted stream materials because their higher density, higher thermal conductivity and generally weaker mechanical strength once solidified make them less desirable candidates for heat shield applications.

Hot Hawaiian tephra output from the ROxygen generation I oxygen production reactor.



High Temperature Polymer Binder



- A high temperature silicone RTV was investigated as a binding agent for the regolith.
- Several RTV/regolith ratios were fabricated.

Regolith heat shield test sample made
From JSC-1A Lunar simulant using a
high temperature silicone RTV
binder.



Flame Impingement Testing



- KSC has fabricated furnace sintered and RTV bound test samples using both JSC-1A Lunar and JSC-1 Martian regolith simulants.
- These samples were evaluated by being subjected to flame impingement tests (via a welding torch).
- All samples (sintered and RTV bound) had good results from the flame testing.



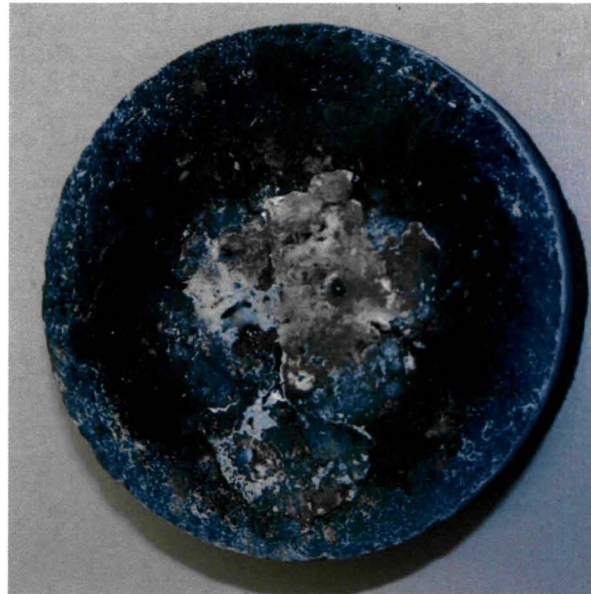
Test sample made from JSC-1A Lunar simulant and 20% silicone RTV undergoing flame impingement testing.



Flame Impingement Testing



- The torch ($\sim 2200^{\circ}\text{C}$) was 6" away from the front surface of the test samples.
- Each sample was exposed for five minutes.
- Maximum rear surface temperature (measured several minutes after test end) was 52.9°C .



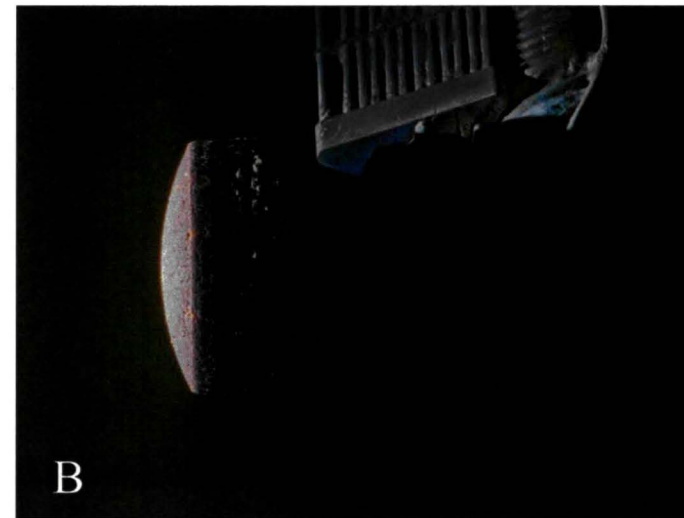
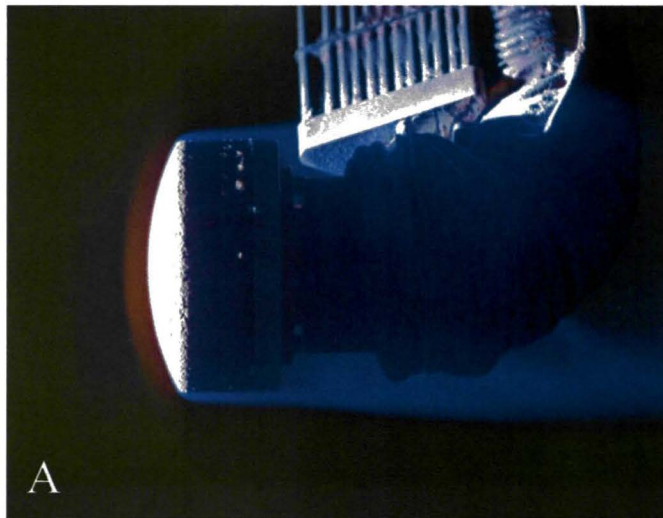
Front surface of RTV bound sample after flame impingement test showing charring and some ablation.



Arc Jet Testing



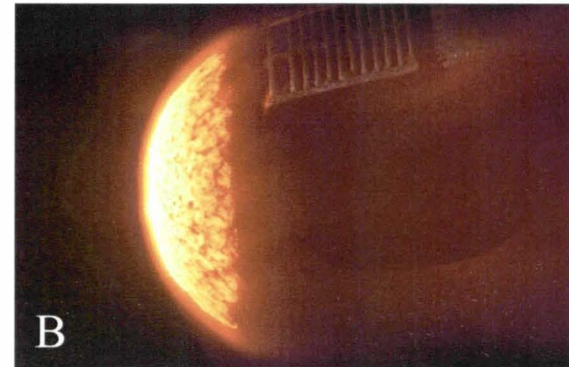
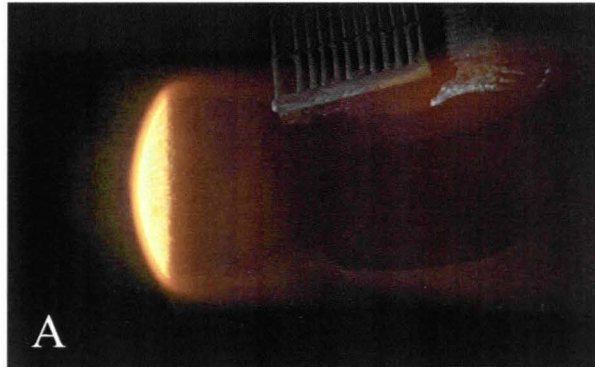
- KSC fabricated ten regolith simulant coupons for testing at the arc jet facility at Ames Research Center
- The arc jet facility can model the thermal and kinetic environment of atmospheric entry via high speed plasma impingement.



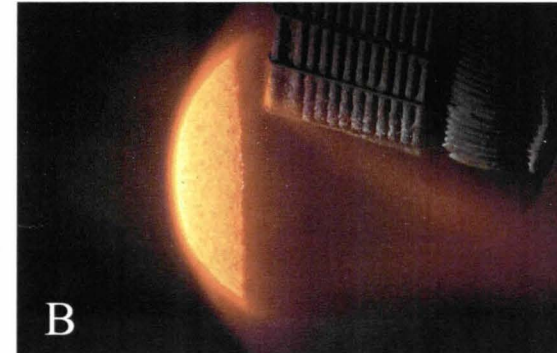
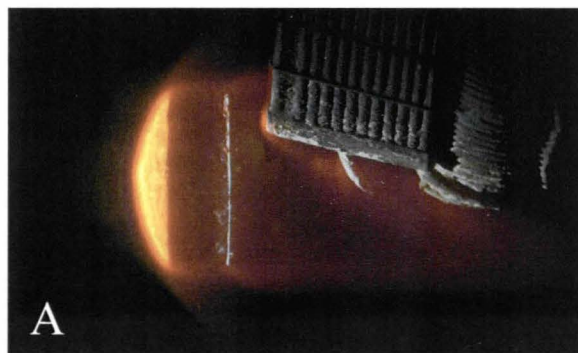
A. JSC-1 Mars/30% RTV-655 at the start of run. B. The same sample at the end of a 150 second exposure at 48 W/cm^2 showing little or no melting or ablation.



Arc Jet Testing



A. JSC-1A Lunar/15% RTV-655 at the start of run. B. The same sample at the end of a 240 second exposure at 92 W/cm^2 showing melting and flow of its surface.



A. JSC-1AC Lunar Sintered "B" at the start of run. B. The same sample at the end of a 300 second exposure at 92 W/cm^2 showing melting and flow of its surface.



Arc Jet Testing

- In the higher heating condition (92 W/cm^2 – equivalent to space shuttle re-entry) ablation and melting of front surfaces were noted.
- All ten samples (sintered & RTV bound) provided adequate dynamic and thermal protection to their rear surfaces (maximum temperature $\sim 262^\circ \text{ C}$ recorded several minutes after test end).



Architecture



- Initial Architecture benchmark is the Mars NASA Design Reference Architecture (DRA) 5.0 modified to use Mars entry heat shields fabricated on Phobos or Deimos.
- With a TPS mass of 40.7 metric tons and a gear ratio* of 5, the LEO to **Mars Mass savings is 203.5 metric tons.**
- Using expendable launch vehicles (~\$8,800/kg) the cost savings per Mars mission is \$1.79 Billion.
- With 10 crew rotations and 10 cargo missions in a Mars campaign using the regolith heat shields, the total cost savings would be **about \$35.8 billion.**

* Gear ratio is the ratio of mass required in LEO to deliver one mass unit to Mars orbit.



Design Reference Architectures

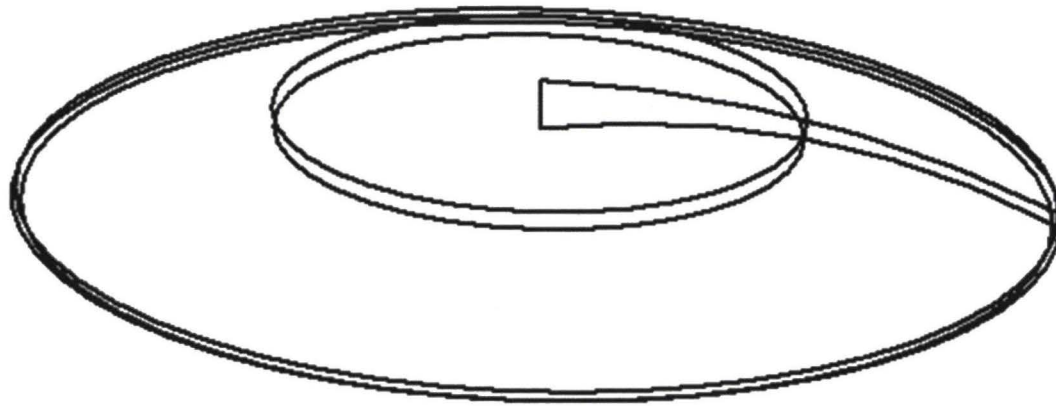
- Architecture I – In Situ Heat Shield Fabrication at Phobos/Deimos for Earth-bound Mars Return Spacecraft and Mars EDL of Surface Exploration Craft.
- Architecture II – Lunar Heat Shield Fabrication Facility for Moon-Earth Returns and Moon-Mars Missions.
- Architecture III: In Situ Heat Shield Fabrication at Asteroid for Earth-bound Spacecraft.



Architecture



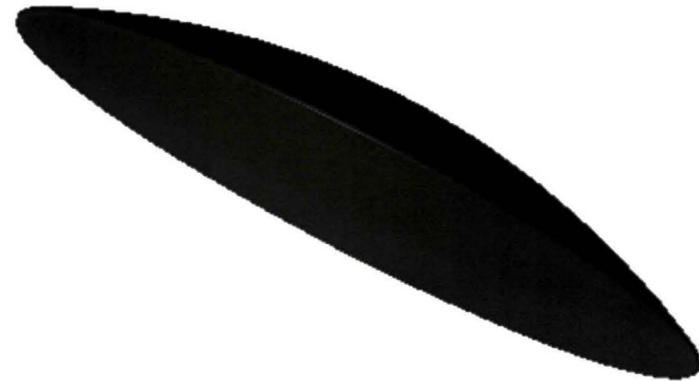
5.0 m diameter



Max thickness: 0.25 m

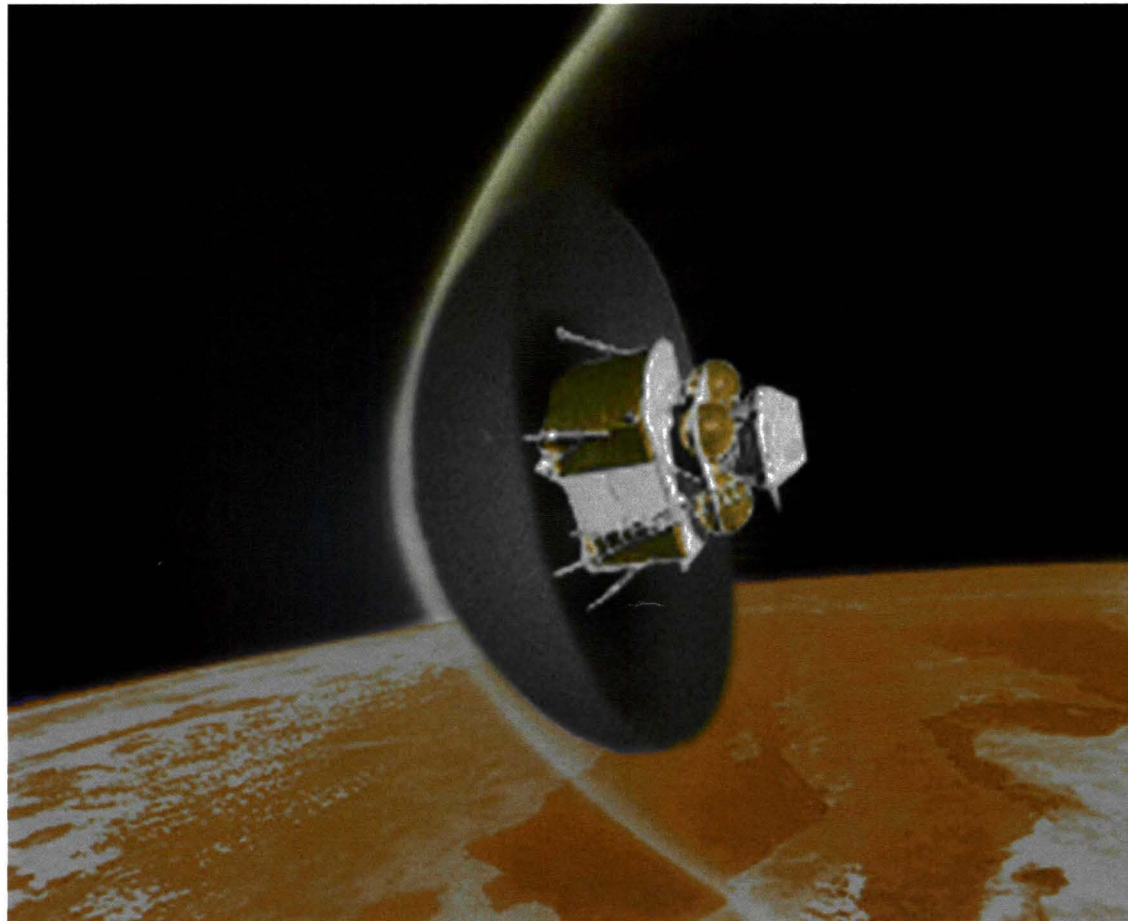
Mass: 2.3 mT

Blended Conic Elliptical Heat
Shield Notional Concept





Artist's Concept of a Regolith-Derived Heat Shield





Summary

- Building a viable heat shield in-situ from regolith will greatly reduce the transport costs of Missions to Mars or other bodies where atmospheric entry is required.
- Three in-situ fabrication techniques Were investigated to build the heat shields. Full melt ISRU generated waste stream was eliminated due to high thermal conductivity and brittleness.
- Test samples of sintered and RTV bound formulations performed well in flame impingement and arc jet testing. Further work will be needed to optimize processes.
- Architectures are being developed for optimal use of regolith derived heat shields.



We would like to acknowledge NIAC, the Kennedy Space Center, and Ames Research Center for their support of this project.

Questions?